Traditional phenological knowledge:

Literature review and case study descriptions of cultural resilience in fire adapted ecosystems by tribal college faculty in the southern Rockies

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I. Abstract

Every ecosystem in North America has been affected to some extent by a fire regime manipulated by indigenous peoples. Indigenous peoples ignited fires to fulfill a wide variety of subsistence and cultural purposes, as a means of modifying the environment for their own survival. The objective of fire and fuels management in the U.S. is no longer to support the subsistence economy of human beings, but to minimize risk to human settlements, while also striving to enhance ecosystem integrity, productivity, and biodiversity. It is in this capacity that traditional knowledge of fire, including traditional phenological knowledge (TPK), could be an invaluable resource for fire and fuels managers. TPK involves an intimate understanding of the timing of growth, development, and reproduction and migration of organisms that generally occurs in a predictable sequence based on environmental determinants such as day length, temperature and moisture. Rooted deeply in a given place, this rich temporal knowledge of biota, landscapes, weather, seasonal cycles, and the associated links with culture and land uses is an integral part of traditional burning regimes around the world. The same traditional fire management strategies that were used to minimize risk while increasing biodiversity and productivity for subsistence could also be used to enhance human safety and well-being while maintaining biodiversity for goals of ecosystem integrity. While the incorporation of traditional knowledge is not a cure-all for problems of fuel accumulation and structural changes that have accompanied a century of fire suppression compounded by the effects of climate change, traditional knowledge should be a fundamental part of strategies for restoration of ecosystem health and human adaptation to changing fire regimes.

In practice, however, inadequate means to organize and communicate traditional knowledge with scientists and managers can limit its effective inclusion in management decisions, requiring novel approaches to cross-cultural communication and collaboration. We propose that Participatory Geographic Information Systems (PGIS) is one means of providing an organizational platform for the recovery, retention, and cross-cultural communication of traditional knowledge vital to fire and fuels management, while preserving its linkages to its broader cultural contexts. A PGIS system called Mapping Meanings (Map-Me), developed cooperatively by the Aldo Leopold Wilderness Research Institute and the University of Leeds, has already been applied for examining and resolving contentious issues surrounding fire and fuels management to support restoration of fire and in assessing community attitudes toward expected impacts of climate change. The primary objectives of this exploratory project were to 1) conduct a comprehensive literature review on the topics of TPK and knowledge integration, particularly with respect to fire management; 2) build new collaborative research partnerships, and expand upon those existing, with tribal college faculty and other tribal experts across the Intermountain West; 3) in collaboration with tribal partners, compile several case studies of the potential application of traditional knowledge for social-ecological adaptation to changing fire regimes in a contemporary context, using Map-Me as an integrative tool; 4) conduct education and outreach initiatives to enhance research capacity at tribal colleges and university programs; 5) further develop the functionality and capacities of Map-Me for expanding research applications; and 6) drawing on the literature review, findings from case studies and education-outreach initiatives and significant technical advancements of the Map-Me tool, propose a series of new questions and hypotheses to guide future research initiatives on the incorporation of traditional knowledge into contemporary fire and fuels management.

II. Background and Purpose

Many have argued that the time has come to engage traditional fire practitioners in solving problems of global significance (e.g., Kimmerer & Lake, 2001; Mason et al., 2012; Huffman, 2013; Voggesser et al., 2013). Traditional knowledge of fire holds great promise for informing contemporary fire and fuels management strategies that will increase social-ecological resilience of fire-adapted ecosystems in a time of rapid environmental change.

Traditional fire knowledge

A recent, extensive review of traditional fire knowledge (TFK) systems from 27 countries on six continents around the world identified 69 distinct elements of TFK, illuminating its depth and complexity (Huffman, 2013). At local and regional scales, TFK entails a multifaceted understanding of how subsets of these multiple elements interact and influence one another; producing many pyrogeographies of considerable nuance and sophistication (Huffman, 2013). Cultural fire regimes have emerged as a result of time-tested knowledge regarding the effects of fire on culturally valued resources, both for increasing resource predictability and promoting ecosystem resilience to changes in climate (reviewed by Voggesser et al., 2013). As emphasized by Kimmerer and Lake (2001), fire was applied to the landscape in a carefully considered manner that would "…minimize its destructive nature while harnessing its creative power" (p. 39). In addition to human-ignited fire regimes, tribal cultures have adapted their subsistence strategies and socio-economic systems in response to climate and changing non-anthropogenic fire regimes for millennia. They observed and adapted to the effects of fire on ecological processes at various scales, from local habitats to landscapes encompassing diverse ecosystems (reviewed by Voggesser et al., 2013). Traditional knowledge was used not only to inform fire prescription, but to inform adaptation to wildfire events.

Traditional phenological knowledge

A key element of traditional burning regimes included traditional phenological knowledge (TPK), an intimate understanding of the timing of growth, development, and reproduction and migration of organisms that generally occurs in a predictable sequence based on environmental determinants such as day length, temperature and moisture (Lantz & Turner, 2003; Turner & Clifton, 2009; Prober, O'Connor & Walsh, 2011). Phenological knowledge is among the top twelve most commonly identified elements of traditional burning regimes around the world (Huffman, 2013). Studies about TPK mirror the relatively recently formalized science of phenology, the study of recurring plant and animal life cycle stages, particularly as they relate to weather and climate (Schwartz, 2013). Changes in the timing of phenological events like flowering, insect emergence, and bird migrations are among the most sensitive biological responses to climate change. Across the world, many spring events are occurring earlier- and fall events are happening later- than they did in the past; however, not all species and regions are changing at the same rate, leading to critical mismatches in timing. It is argued that the study of plant and animal responses to climate make phenology a leading indicator of climate change impacts (USANPN, 2014). However, the much longer timescale, and broader, more inclusive nature of TPK may offer even better insights and solutions for climate change adaptation. Lantz and Turner (2003) defined TPK as:

> "All knowledge of biological seasonality, including the observation of life cycle changes in specific plant or animal species to indicate the timing of the onset of

> growth stages in other species, linguistic references to phenological events, traditional conceptions of time as they relate to seasonal change, and spiritual beliefs about cause and effect relationships of seasonal change" (p.265).

Traditionally, people relied on their knowledge of seasonal cycles to secure an ongoing supply of food, water, medicines, and other resources, interpreting phenological indicators to predict important events and signal when to pursue different cultural activities, including fire ignition (Prober, O'Connor & Walsh, 2011). As such, TPK reflects both a "range of variation in species abundance and productivity" and "norms and baselines for seasonal events" (Turner & Clifton, 2009, p. 185). Rooted deeply in a given place, this rich temporal knowledge of seasonal cycles, and the associated links with culture and land uses, is an integral part of traditional burning regimes around the world.

The objective of fire and fuels management in the U.S. is no longer to support the subsistence economy of human beings, but to minimize risk to human settlements, while also enhancing ecosystem integrity, productivity, and biodiversity. It is in this capacity that traditional knowledge could be an invaluable resource for fire managers. The same traditional strategies that were used to increase biodiversity and productivity for subsistence while minimizing risk could also be used to enhance and maintain biodiversity for goals of ecosystem integrity and human safety (Kimmerer & Lake, 2001). While the incorporation of traditional knowledge is not a cure-all for problems of fuel accumulation and structural changes that have accompanied a century of fire suppression compounded by the effects of climate change, traditional knowledge should be an integral part of strategies for restoring ecosystem integrity and informing human adaptation to changing fire regimes.

Knowledge integration for social-ecological resilience

To manage the scope, complexity and uncertainty of rapidly changing environmental issues today, it is imperative to take account of different types and sources of knowledge. Recognizing that modern problems cannot consistently be solved with singular, mechanistic, science-centered solutions, successful management increasingly depends on pluralistic courses of action that include partnerships between managers and locally knowledgeable groups, such as indigenous people (e.g., Moller et al., 2004; Higgs, 2005; Fraser et al., 2006; Wehi, 2009). In environmental management, this combining of different knowledges is most commonly referred to as knowledge integration. Despite profound theoretical, political, and practical challenges, there is widespread and growing interest in, as well as legislative and policy support for, knowledge integration that includes traditional knowledges and science. This national and international attention is rapidly growing along several lines of argument, including the enhancement of biocultural diversity, promotion of social justice for indigenous peoples, supplementation for scientific studies, and provision of new prescriptions for environmental management (reviewed by Bohensky & Maru, 2011). While these arguments are neither mutually exclusive nor entirely harmonious, all acknowledge that we need new ways to address longstanding as well as emerging complex social-ecological challenges.

It is also argued that knowledge integration can build social-ecological resilience, the ability of a social-ecological system to withstand disturbance without changing its fundamental structure, function, feedbacks and identity, and to remain flexible in response to changing environmental and social contexts (Redman & Kenzig, 2003; Walker et al., 2006). The resilience view holds

that the management of complexity and uncertainty in social-ecological systems can benefit when diverse types of knowledge are combined, and argues that there is opportunity in complexity; that the shifting and flux of traditional and scientific worldviews that breed complexity can in fact offer a chance to revisit old problems and paradigms, and collectively construct new models of how the world works (Folke et al., 2005; Houde, 2007; Plummer & Armitage, 2007). Traditional knowledge, in particular, is seen as "…offering (re)new(ed) ways of thinking that have and will lead to new insights and practices" in environmental management (Evering, 2012, p. 358). Knowledge integration is not simply about achieving better management outcomes, but also about revising assumptions. It is not only about products, but developing new processes of collaboration and learning, building capacity to manage resources in cross-cultural contexts, and adapting management strategies in a time of rapid environmental and social change.

Knowledge integration in U.S. fire and fuels management

In the U.S., fire and fuels management has incorporated traditional knowledge on a very limited basis, despite considerable traditional knowledge of fire regimes (Anderson, 2005; Lake, 2007; Carroll et al., 2010). A growing number of federal, state, and tribal governments and academic institutions are holding workshops to discuss the potentials and challenges of knowledge integration for fire management (e.g., Alvarado et al., 2011; Mason et al., 2012), while others are conducting research as to the feasibility of such integration (e.g., Ray et al., 2012). However, little integration work has actually been performed and assessed.

III. Study Description and Location

This project sought to build upon the gathering momentum in support of knowledge integration for fire and fuels management in the United States. Across the U.S. and worldwide, much traditional knowledge has been lost to time and forced assimilation, but much persists in the oral tradition and practices of contemporary native communities (Kimmerer & Lake, 2001). In practice, however, inadequate means to organize and communicate traditional knowledge with scientists and managers can limit its effective inclusion in management decisions. Many argue that traditional and scientific ways of knowing are radically asymmetrical, and in the extreme, incommensurable, in addition to numerous other place-specific environmental, social, and political issues (Nadasdy, 1999; Atran, 2001; Verran, 2001; Cruikshank, 2005; Dickison, 2009). Such challenges require novel approaches to cross-cultural communication and collaboration.

We propose that Participatory Geographic Information Systems (PGIS) is one such means of providing an organizational platform for the recovery, retention, and cross-cultural communication of traditional knowledge vital to contemporary fire and fuels management, while preserving its linkages to its broader cultural contexts. PGIS has the capacity to preserve and integrate such knowledge by providing a mechanism for the involvement of multiple stakeholders in the description of and decision-making about processes related to space (Kingston, 2007). From the perspective of participatory action research (e.g., Chevalier & Buckles, 2013), PGIS acts counter to the approach of command and control to environmental management issues by including a wide range of stakeholders in the planning process, with the goals of including diverse perspectives on the problem and promoting shared knowledge, understanding and trust between all parties to avoid conflict and/or facilitate conflict resolution.

From an information technologies perspective, PGIS provides a means to store, manage and use contributed geospatial data through digital media, compare the patterns of these data to other GIS datasets, and enable data sharing amongst stakeholders (Elwood 2006; Heywood et al., 2011). Also, when coupled with text data (i.e., participants' written comments), PGIS can allow the designation of landscape properties on the basis of the meanings people ascribe to locations, and thus lead to a better understanding of spatial relationships between tangible and intangible elements of humanized ecosystems (Carver et al., 2001).

We worked specifically with a PGIS tool called Mapping Meanings (Map-Me), developed cooperatively by the Aldo Leopold Wilderness Research Institute and the University of Leeds. Earlier versions of Map-Me have already been applied for examining and resolving contentious issues surrounding fire and fuels management to support restoration of fire and in assessing community attitudes toward expected impacts of climate change on benefits flowing from protected areas (Carver et al., 2009; Watson et al., 2009). Map-Me (www.map-me.org) allows survey participants to answer standard demographic and thematic questions and then proceed to a number of geospatial questions using a "spraycan" tool on a Google Maps layer, also providing comments about the places they have sprayed. The spraycan tool enables participants to locate phenomena on a map in a vague or imprecise manner. Further, Map-Me can now be coupled with Natural Language Processing, an Artificial Intelligence approach that allows for semantic analysis of large amounts of text data, enabling a greater efficiency of interpretation than other qualitative analysis methods (e.g., manual thematic coding). Data collected using Map-Me can also be statistically compared to other datasets and GIS layers, such as land cover, land use, and fire regime history.

With PGIS as our primary methodology, we contend that facilitating the combination of experiential with experimental knowledge and fostering complementarity of different knowledge systems can contribute to more resilient social-ecological outcomes in fire and fuels management. The primary objectives of this exploratory project were to: 1) conduct a comprehensive literature review on the topics of TPK and knowledge integration, particularly with respect to fire management; 2) build new collaborative research partnerships, and expand upon those existing, with tribal college faculty and other tribal experts across the Intermountain West; 3) in collaboration with tribal partners, compile several case studies of the potential application of traditional knowledge for social-ecological adaptation to changing fire regimes in a contemporary context, using Map-Me as an integrative tool; 4) conduct education and outreach initiatives to enhance research capacity at tribal colleges and university programs; 5) further develop the functionality and capacities of Map-Me for expanding research applications; and 6) drawing on the literature review, findings from case studies and education-outreach initiatives and significant technical advancements of the Map-Me tool, propose a series of new questions and hypotheses to guide future research initiatives on the incorporation of traditional knowledge into contemporary fire and fuels management.

A. Review of Literature. The project began with a comprehensive literature review of the topic, divided into two manuscripts of increasing specificity. The first manuscript, (*Re)new(ed) ways of sustaining the commons: the problems and potentials of integrating indigenous and scientific knowledge in environmental management*, examines the rapidly increasing trend worldwide of integrating traditional and scientific knowledges in environmental

management. The second manuscript, *Identifying opportunities for utilizing traditional phenological knowledge to support management of social-ecological systems vulnerable to changes in climate and fire regimes*, focuses more specifically on the subset of traditional knowledge known as TPK, and its potential and realized applications for social-ecological adaptation to changing fire regimes.

B. Building and Expansion of Tribal Partnerships. This project also sought to build new collaborative research and teaching partnerships, and expand upon those existing, with tribal college faculty and other tribal experts across the Intermountain West. New partnerships were created in New Mexico, Montana, and eastern Washington (Figure 1).

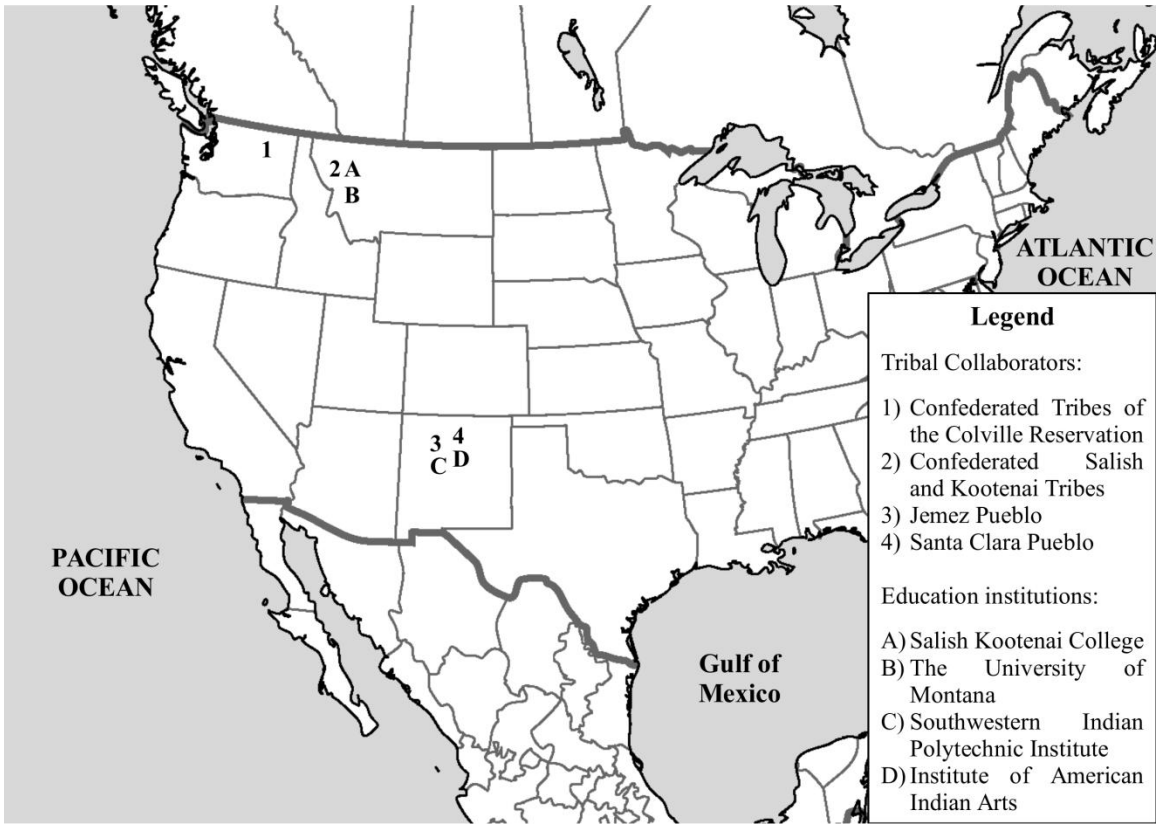

Figure 1. Locations of tribal collaborators and education institutions in the Intermountain West of North America.

C. Compilation of Case Studies. Case studies with interested tribal collaborators proceeded as opportunities availed. Case studies included:

- *Traditional knowledge for the post-fire rehabilitation of Santa Clara Pueblo, New Mexico*.
- *Traditional knowledge for the reduction of hazardous fuels around Jemez Pueblo, New Mexico.*
- *A case study on climate change impacts to tribal resources (water, vegetation, and fire regimes) in the Jocko Landscape on the Flathead Indian Reservation, Montana*.

- *Developing a strategy for monitoring the effects of fire management activities on culturally important plant species on Colville National Forest lands bordering the Colville Indian Reservation, Washington.*

D. Education and Outreach Initiatives. Education and outreach initiatives with interested tribal college and Native Studies faculty proceeded as opportunities availed. Initiatives included:

- *Sparking new research ideas through Participatory GIS Training at Salish Kootenai College, Montana. March 7th, 2014.*
- *Master's of Arts in Environmental Studies portfolio plan: applications of traditional ecological knowledge to ecological management, Environmental Studies, The University of Montana.*
- *Circular seasonal calendars as organizational frameworks for cross-cultural communication of TPK through artistic representation, Institute of American Indian Arts, New Mexico.*
- *Promoting multi-agency collaboration and student training through a PGIS Workshop at the 2014 Tribal GIS Conference, Southwestern Indian Polytechnic Institute, New Mexico.*

E. Further Development of the Map-Me Tool. A major impediment to the analysis of text responses that participants attach to landscapes is the allocation of meaning to vague descriptions and the uncertain definitions that derive from it. To address this challenge, this project coupled Map-Me with Natural Language Processing and data-mining techniques to facilitate the semantic synthesis, interpretation and pattern-recognition of geo-referenced text data by means of partially or fully automated mechanisms.

F. Development of New Research Questions and Hypotheses. Based on the body of knowledge obtained through the literature review (including the lens of resilience theory), case studies, education and outreach initiatives, and the significant technical advancements of the Map-Me tool, the research team convened with tribal collaborators to develop a set of new questions and hypotheses to guide future research initiatives at each location. These are organized by case study and education/outreach initiative in the following section.

IV. Key Findings

Key findings and outcomes from each case study and education/outreach initiative are summarized in the following sub-sections.

Traditional knowledge for the post-fire rehabilitation of Santa Clara Pueblo, New Mexico. In recent years, the Jemez Mountains in northwestern New Mexico have been hit by a series of natural disasters that have seriously affected the ecosystems and socio-economic dynamics of local settlements, consisting mainly of Pueblo communities, worsening their already difficult situations in relation to employment and economic development. From 2011 (Las Conchas Fire, 150,000 acres) to 2013 (Thompson Rige Fire, 24,000 acres; Diego Fire, 3,500 acres) nearly 180,000 acres of forest land in the Jemez have been destroyed by wildfires, in addition to a series

of drought-and-flooding events that have swept away the organic soils, making the process of forest and watershed recovery even more challenging. Areas of such devastation are found on the Santa Clara Pueblo reservation. Much of Santa Clara Pueblo's protected area has been burned, along with archeological and historical cultural sites related to the Pueblo on adjacent public lands. Further, Santa Clara Creek and watershed have suffered from extreme erosion.

Santa Clara Pueblo holds a rich store of traditional knowledge about its ecosystem that can make significant contributions to landscape and streambed restoration efforts. In order for the community and lands to recover, there is a tremendous need to incorporate traditional knowledge and cultural concerns at all levels of planning, fire response, and post-fire restoration. However, there are many barriers to such incorporation. These include limited coordination between state, federal, tribal and local governments that prevents the incorporation of traditional knowledge in recovery initiatives; and a tendency toward uniform prescriptions and one-size-fits-all practices that exclude traditional knowledge and often present environmentally and culturally inappropriate approaches to post-fire flood control. In consultation with natural resource managers at Santa Clara Pueblo, we posed the question: How can traditional knowledge be integrated with best post-fire restoration science practices to contribute to the recovery of Santa Clara Pueblo? We developed several hypotheses, including: (1) PGIS will improve coordination between governments by fostering the assembly of traditional and scientific knowledges for post-fire rehabilitation; (2) traditional water catchment systems will provide a more effective, environmentally sound, and culturally appropriate means of post-fire flood control than uniform prescriptions, with PGIS helping to determine where such catchments should be located; and (3) PGIS will enable traditional knowledge to inform rehabilitation efforts by helping to identify plant species that are best suited to current climatic conditions on a local scale.

Traditional knowledge for the reduction of hazardous fuels on and around Jemez Pueblo lands, New Mexico. The high likelihood of catastrophic wildfires that have devastated Santa Clara Pueblo and wildlands now threatens to impact Jemez Pueblo, located only 67 miles (108 kilometers) west of Santa Clara Pueblo by car, across Valles Caldera Natural Preserve. Public bodies that manage land in this immediate region include Puebloan governments, the National Park Service (Bandelier National Monument), Forest Service (Santa Fe National Forest, San Pedro Parks, St Peters Dome), and the Valles Caldera Trust. In a meeting including representatives from Jemez Pueblo and Valles Caldera Trust, we asked: How can traditional knowledge be integrated with contemporary hazardous fuels reduction practices to contribute to the protection of Jemez Pueblo? We hypothesized that, (1) PGIS will enhance collaboration between the Jemez community and management agencies, enabling the adoption of more locally and culturally appropriate fire and fuels management actions; (2) PGIS will incorporate a greater number insights on historical uses and purposes of fire (e.g. agriculture, grazing, clearing of forests, cultural practices) into fire and fuels management on Jemez Pueblo lands; (3) PGIS will document a wider range of perceptions from Jemez residents about good forest structure and fire management (e.g. if and where prescribed fire should be restored); (4) geovisualization of the cultural impacts of fire can inform managers of areas of cultural sensitivity and concern that require special treatment; and (5) traditional knowledge about prescribed fire will improve efforts to reduce hazardous fuels by identifying the most suitable locations and conditions under which to implement low-intensity burns.

A case study on climate change impacts to tribal resources (water, vegetation, and fire regimes) in the Jocko Landscape on the Flathead Indian Reservation, Montana. The Forestry Department of the Confederated Salish and Kootenai Tribes (CSKT) is developing a section of the current Flathead Indian Reservation Forest Management Plan that prescribes adaptive planning to mitigate negative effects of climate change on tribal forest lands, particularly with respect to changing fire regimes. The overall objective of this project was to determine climate change impacts to tribal resources in the Jocko Landscape Unit as outlined in the management plan. The Map-Me tool was employed by the CSKT Forestry Department to gather perceptions from relevant tribal and non-tribal residents and natural resource managers about how the landscape has changed over time, the causes of those changes, and obstacles to achieving desired future conditions. Participants were also asked whether and how traditional knowledge might be applied to help address these challenges. Map-Me output was analyzed to illustrate both cultural and biophysical attributes of the landscape.

We found that tribal and non-tribal residents differed in their perceptions of where prescribed fire should be implemented. Tribal members mostly identified the southern section of the Mission Mountains Wilderness area on the eastern side of the Jocko landscape unit, whereas non-tribal members mostly identified the Middle Jocko Valley. Tribal and non-tribal residents also differed with respect to the land-use classes that they reported having undergone change in recent years. Tribal members mostly identified areas at the top of the Mission Mountains with a high frequency of natural ponds and mountain woodlands, whereas non-tribal members mostly identified herbaceous lands between the Jocko River basin and mountain woodlands. Whereas tribal and non-tribal residents different in their perceptions of where the most change has occurred and where prescribed fire should be implemented, both groups suggested that traditional burning practices should be reintroduced into the landscape. Yet, both groups expressed uncertainty as to how this knowledge might be incorporated into management plans. In cooperation with the CSKT Forestry Department, we asked: How can traditional knowledge be integrated into the CSKT Forest Management Plan? Hypotheses included: (1) PGIS is a means to organize and compare the geographical features of traditional fire knowledge about the landscape with local fire management plans implemented by management agencies since the middle of the 20th century, providing further insights into how these knowledge systems and approaches have complemented and/or contrasted with each other over time; and (2) from an historical perspective, demography-based disagreements over fire and fuels management can be linked to the evolution of geospatial properties of the local landscape (e.g., land use, land use, fire regime histories), providing a multidimensional, complex, and spatially-aware interpretation of public responses.

Developing a strategy for monitoring the effects of fire management activities on culturally important plant species on Colville National Forest lands bordering the Colville Indian Reservation, Washington. In 2012, the *Northeast Washington Forest Vision 2020* project (NWFV 2020, 2011) was selected for funding under the Forest Service High Priority Restoration Program. In 2013, Vision 2020 was assimilated into the Collaborative Forest Landscape Restoration Program (CFLRP) to ensure continued funding. The Vision 2020 proposal makes a compelling case for restoring the landscape to more traditional fire regimes by increasing the forest's resilience to natural disturbance, breaking up the homogeneity of the landscape mosaic, thinning overcrowded, suppressed stands, and enhancing the development of fire-resistant

late/old forest structure. A key objective of these activities is fewer and smaller wildfires, and reductions in the cost of firefighting and risk of loss of lives and property. Questions that the monitoring plan seeks to address include: How have the past and present fuels treatments implemented by Colville National Forest influenced cultural plants of interest to the Confederated Colville Tribes (CCT) and the likelihood of a large fire event traveling from Forest Service lands onto the Colville Reservation and Colville tribal allotments within the CFLRP boundary? How can Colville National Forest use fuel treatments to maintain and enhance cultural plants of interest to the CCT while reducing the likelihood of a large fire event damaging the CCT's identified values at risk? In discussions with representatives from the Confederated Colville Tribes and Colville National Forest, we proposed: (1) PGIS is a means of organizing CCT members' knowledge of past, present, and desired future distributions of culturally important plant species and their perceptions of highest-risk areas on Colville lands; (2) PGIS provides a mechanism for comparing this knowledge with the effects of fuels treatments over time as part of the monitoring strategy.

Sparking new research ideas ideas through PGIS Training at Salish Kootenai College, Montana. March 7th, 2014. Salish Kootenai College (SKC) students, GIS personnel from the Confederated Salish & Kootenai Tribes' (CSKT) Natural Resources Department, the CSKT Forestry Department, and Ethnotech LLC, a cultural resource consulting and heritage education firm, attended a one-day Special Topics Seminar on PGIS at SKC. The seminar, developed cooperatively by the University of Leeds in the UK, CSKT and the Aldo Leopold Wilderness Research Institute, centered on the Map-Me tool. The purpose was to inform participants about the Map-Me tool, train them in its use, facilitate group discussion of potential applications of Map-Me for exploring environmental issues in their area, and foster new independent research projects. The first half of the seminar included a 45-minute lecture on PGIS fundamentals and a 45-minute lecture on PGIS applications, with a focus on case study examples on the Flathead Indian Reservation, including the Mission Mountain Tribal Buffer Zone and the Jocko Landscape Unit. The second half of the seminar included a 30-minute demonstration of Map-Me and a 30-minute brainstorming session about local environmental research questions that might be addressed using this tool. The seminar concluded with a 1-hour Map-Me training session, with small groups each working to generate a new survey that could be used to explore their respective research questions. All participants contributed to the development of new research ideas and applications in the local environment. This seminar represented one in a series of special courses, projects, and workshops that students may complete to earn a Certificate in GIS. To receive credit for the seminar, students continued to work with the GIS instructor at SKC to design their own research projects using Map-Me.

Student projects included: (1) engaging tribal community members in describing the past, current, and desired future distributions of culturally important plant species, such as camas (http://map-me.org/sites/camasstudy/); and (2) engaging tribal community members in identifying the current distributions of curlew, the largest shorebird of grasslands and prairies in North America, whose numbers are in decline (http://map-me.org/sites/mtcurlews/). With CSKT faculty, students, and tribal management representatives, we discussed: What are the benefits of PGIS tools for tribal communities? We hypothesized that: (1): training tribal college students, community members, and natural resource managers in the use of PGIS tools builds their capacity to define and conduct their own research; and (2) training tribal college students,

community members, and natural resource managers in the use of tools PGIS builds their capacity to integrate traditional knowledge into management decisions.

Master's of Arts in Environmental Studies portfolio plan: applications of traditional ecological knowledge to ecological management, The University of Montana. A Master's student in Environmental Studies at The University of Montana developed a proposal for funding to allow her to conduct a Master's project integrating Blackfeet seasonal knowledge from her home in the Blackfeet Nation, Montana, with science and art. We provided mentorship and guidance for her in developing her proposal to include the creation of a visual representation or prototype of a circular seasonal mural depicting this integration, which can later be painted on transferable canvas or as a permanent mural in one of the buildings on The University of Montana campus.

Master's portfolio statement: "The central theme of my portfolio is interdisciplinary. I plan to illustrate the integration of Traditional Ecological Knowledge and Environmental Science. I want to interpret how cyclical processes (phenology) embedded in the ecology of a given place influenced Indigenous people and fostered their existence. I would like to cultivate a sense of awareness of asymmetrical ways of knowing and show how they complement each other and inspire alternative methods of natural resource management. I want to express ways Traditional Ecological Knowledge emphasizes an intimate understanding of natural systems and encompasses an ethical, spiritual and cultural focus, incorporating native language, art and symbolism. Based on those found in different cultures throughout the world, I plan to use an Aboriginal circular seasonal calendar as the foundation for my design I will create a visual representation or prototype, which can then be later painted on transferable canvas or as a permanent mural in one of the buildings on campus. I will provide a written description of elements included in my depiction and information as to how it can be used as an organizational framework for the recovery, retention and cross-cultural communication of Traditional Ecological Knowledge, native language and art."

Circular seasonal calendars as organizational frameworks for cross-cultural communication of TPK through artistic representation, Institute of American Indian Arts, New Mexico. One potential means of facilitating the communication of TPK vital to environmental management is to look to the past. Found in different cultures throughout the world, this knowledge has been represented in the form of circular seasonal calendars (e.g., Figure 2). Whereas the standardized Western or Gregorian calendar focuses on structural time, concepts of time that underpin traditional, indigenous, or local seasonal knowledge emphasize ecological time: cyclical processes that are strongly embedded in the ecology of a given place (Prober, O'Connor & Walsch, 2011). In collaboration with faculty at the Institute of American Indian Arts (IAIA), we have proposed to create an interactive, digital version of a circular seasonal calendar that will serve as a tool for the assembly of indigenous seasonal knowledge of a given place. Dubbed "MapTiMe", the tool will allow participants to depict their knowledge of the timing of important seasonal events, represented as concentric circles (Figure 3). In collaboration with IAIA administration, we have asked, How can circular seasonal calendars facilitate the communication of TPK? We have proposed: (1) circular seasonal calendars will augment, rather than override, other approaches to cross-cultural environmental management such as those with a spatial emphasis; (2) circular seasonal calendars will provide a means for understanding and depicting cultural adaptation to

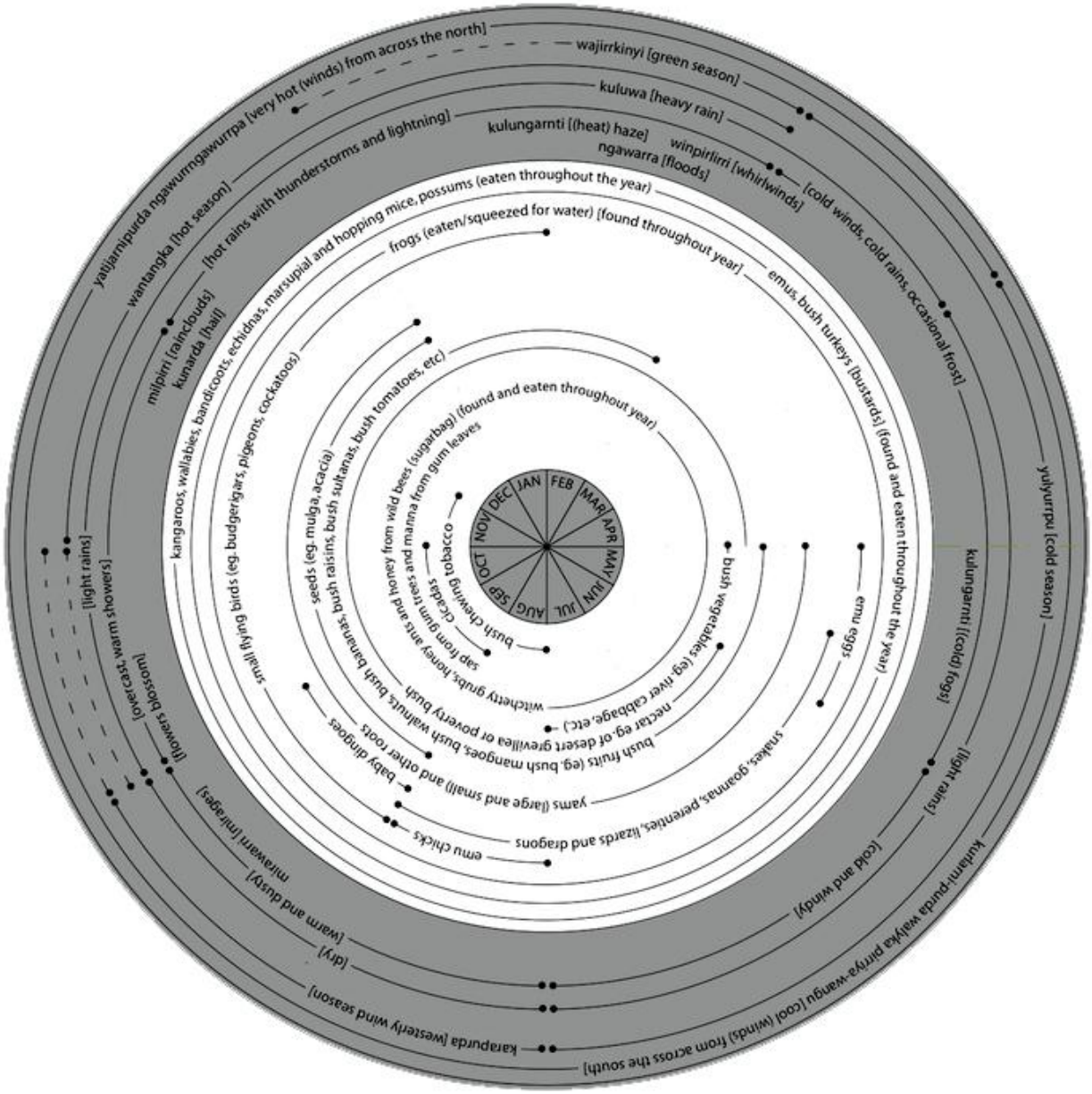

Figure 2. A Warlpiri calendar from central Australia showing a representation of traditional seasonal knowledge framed by the 12-month Gregorian calendar (from Prober, O'Conner, & Walsh. 2011. Australian Aboriginal Peoples' seasonal knowledge: a potential basis for shared understanding in environmental management. *Ecology and Society* 16(2): 12).

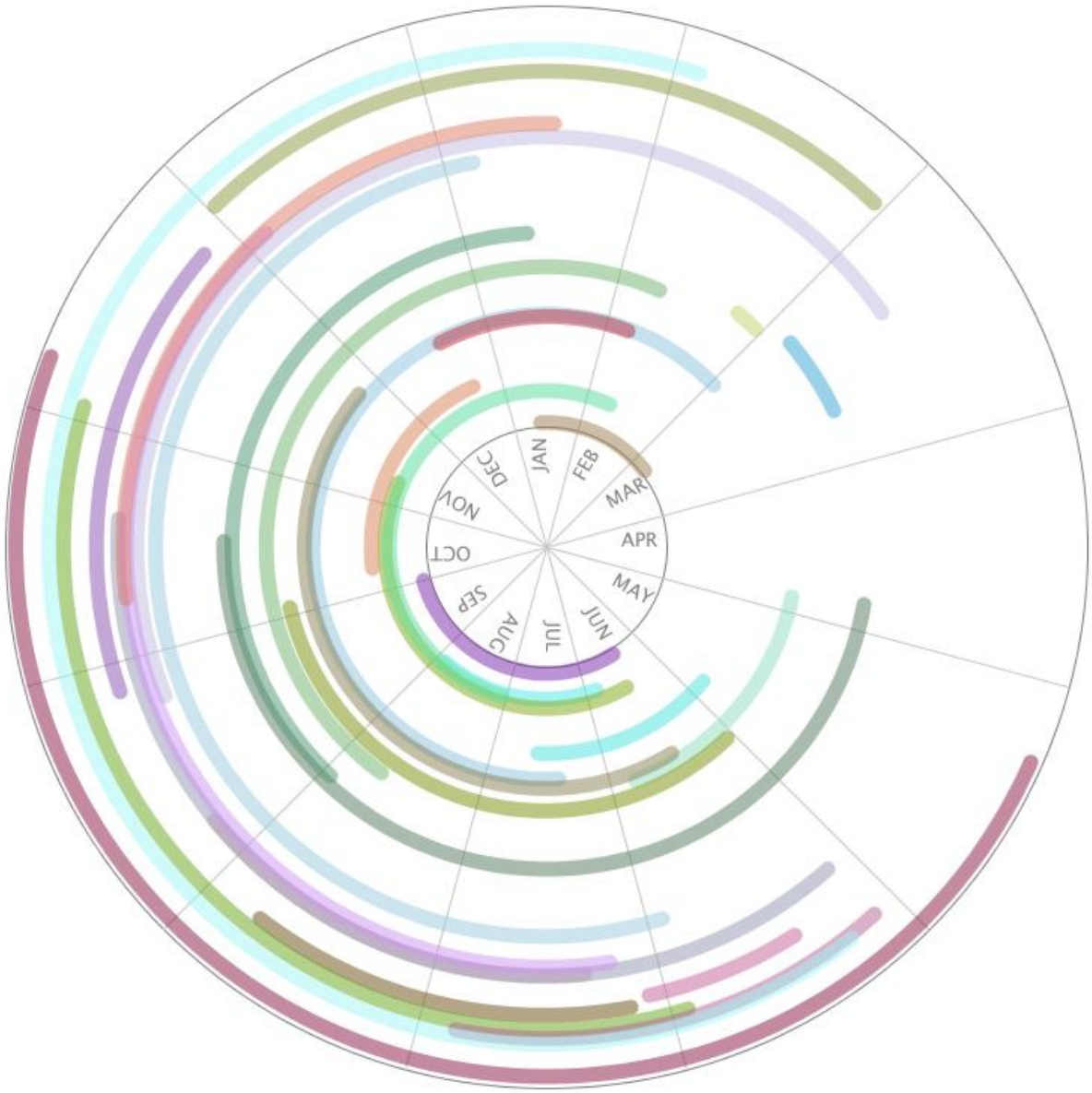

Figure 3. Sample output from proposed "MapTiMe" tool, based on randomly generated data.

climate change and will offer insights into the potential benefits of alternative future adaptive management strategies; and (3) circular seasonal calendars will serve as the basis for beautiful artistic representations and a method of demonstrating to the public and managers how TPK can be applied to resource management decisions.

Supporting multi-agency collaboration and student training and participation through a PGIS Workshop at the 2014 Tribal GIS Conference, Southwestern Indian Polytechnic Institute, New Mexico. In cooperation with faculty and administration at Southwestern Indian Polytechnic Institute (SIPI), we have proposed to offer a pre-conference workshop for attendees of the 2014 Tribal GIS Conference, to be held at SIPI in November 2014. This workshop will provide PGIS training and brainstorming activities that support multi-agency collaboration in the implementation of post-fire restoration and fire and fuels management programs across the Jemez Mountains. As previously mentioned, public bodies that manage lands in this region include Puebloan governments, the National Park Service (Bandelier National Monument), Forest Service (Santa Fe National Forest, San Pedro Parks, St Peters Dome), and the Valles Caldera Trust. Utilizing an approach similar to what we implemented at Salish Kootenai College in Montana (see earlier section), we anticipate that this workshop will: (1) contribute to a greater understanding of the cultural impacts of fire on Tribes across the Jemez Mountains; (2) inform fire and fuels managers of areas of cultural sensitivity and concern that need special treatment; (3) contribute to the design of multi-agency protection and recovery plans for fire-monsoon seasons. In addition, SIPI students will gain exposure to and training in PGIS applications for examining issues in their immediate region.

V. Management Implications

Through this project, we have built upon the gathering momentum in favor of knowledge integration for fire and fuels management in the U.S. Using PGIS as an organizational framework and an integrative tool, we have laid foundations for several new research and education collaborations across the Intermountain West. We now consider our work in light of the implications of fire knowledge integration via PGIS for fire and fuels management, and the notion of fire knowledge integration for social-ecological resilience, more broadly.

Fire knowledge integration and PGIS

A few studies have demonstrated that there are many benefits to integrating traditional and scientific knowledge in a GIS spatial framework, which include incorporating inputs and policies at various levels of spatial aggregation, promoting spatial and temporal thinking about issues and concerns, and creating opportunities for learning and sharing of responsibilities (e.g., Petch et al., 1995; Balram et al., 2004; Bethel et al., 2011; McCarthy et al, 2012; Barlindhaug et al., 2014). However, while a recent, extensive review of traditional fire knowledge systems around the world has been conducted (Huffman, 2013), and fire knowledge integration practices are expanding as discussed, we are unaware of examples of applied spatial knowledge integration research from traditional and scientific knowledge sources to inform decision-making in fire and fuels management.

In order to demonstrate how fire knowledge integration may be used to enhance current decision-making processes, future efforts should focus on collaborative GIS methods for integrating

traditional and scientific knowledges with spatial environmental data in an interactive participatory process for establishing fire management priorities and enhancing current decision-making processes. Such integrated data sets would allow local and technical knowledge experts to share, explore, manage, analyze, and interpret multidimensional data in a standard spatial context in order to develop more informed fire management decisions.

Fire planning decision-support tools that incorporate traditional and scientific bodies of knowledge could provide a more comprehensive means of assessing ecological change that can benefit both ecosystem integrity and human community adaptability. Such research would represent an innovative effort to merge diverse spatial, biophysical, and traditional knowledges about fire into a format suitable for informing current fire decision-support processes at a resolution suitable for localized decision making. It would also engage users directly in the process of analyzing current conditions and anticipated effects of fire-related management efforts. Such combined data sets could provide a more comprehensive assessment of ecological change than is currently utilized in decision making that includes effects on local resource utility value and areas of cultural significance.

By seeking a collaborative partnership in assessing impacts and uses, state and tribal officials as well as scientists engaged in fire management analyses may also gain support from commercial and other users because the latter are brought in as partners to contribute to the sustainability of the ecosystem on which they depend. Such research would strive to continue to increase the dialog and discussion among multiple groups, local ecosystem users and scientists/government officials, fostering mutual respect and knowledge transfer that will be sustained beyond the term of a given study. If such a goal is achieved, local residents may continue to provide researchers with insight, informed suggestions and critique, thus aiding the mapping process and interpretation of mapped images, ultimately helping to inform fire decision-making process for the foreseeable future. Such efforts would address the general lack of understanding of the information value that traditional fire knowledge offers to contemporary management, as well as start to bridge the communication gap that typically exists between scientists and traditional knowledge holders as ecosystems continue to be altered through processes of fire and fuels management and climate change.

Fire knowledge integration for social-ecological resilience

Given the tremendous interest in and support for the argument that knowledge integration builds social-ecological resilience, there is as yet little empirical evidence to support this claim. Based on a recent, extensive review of a decade of international discussion on knowledge integration, Bohensky & Maru (2011) found that little of the literature engages substantively with resilience theory, and where it does, the relationship between traditional knowledge, integration and resilience is not particularly clear. While there has been a strong theoretical basis and a few empirical studies supporting this argument, their analysis points to the need to further confront this claim with real-world evidence. This represents a key research frontier for the theory and practice of knowledge integration, in fire and fuels management and beyond. Following Bohensky & Maru's (2011) line of questioning about knowledge integration more generally, we ask: Does TFK itself and/or its integration with science build resilience in fire-adapted social-ecological systems? Which fire-adapted social-ecological systems does knowledge integration build the resilience of, on what scales in time and space, and for whom? Given the numerous

biocultural, political, scientific, and other arguments in favor of knowledge integration, resilience theory may not necessarily offer the most useful perspective; however, its emphasis on novelty and innovation in human interactions with the world has something significant to offer as the practice of knowledge integration continues to evolve (Bohensky & Maru, 2011).

Another important area of inquiry includes the resilience of TFK sytems themselves. Given the multiple elements of TFK and the specialized combinations that characterize the pyrogeograhies of different localities, Huffman (2013) asks, "[What] is the extent to which traditional fire managers can reorganize and reapply these elements to meet their needs as local social-ecological systems change [?]. Will adapting TFK be ecologically and socially feasible? In what ways will TFK systems as a whole be resilient in the face of climate change and in what ways will they be vulnerable?" (p. 8). We add, to what extent will knowledge integration help to TFK to be preserved, and to adapt? How can TFK and its identify be maintained, yet also enriched through its interaction with science?

VI. Relationship to other recent findings and ongoing work on this topic

A growing number of governmental, academic and other institutions in the U.S. are convening to discuss the challenges, potentials, and feasibility of knowledge integration in fire management, but little integration work has actually been performed and assessed.

Knowledge integration for more holistic fire management

There are some exceptions to the current sparseness of on-the-ground implementation in the U.S. Active efforts are underway to recover, rejuvenate, and/or share traditional fire knowledge, with the intent of expanding the application of traditional practices in landscapes where traditional fire management was once the norm (Huffman, 2013; Voggesser *et al*., 2013). Several landscapes in the U.S. Fire Learning Network (USFLN) have begun to rejuvenate their traditional fire knowledge systems. The USFLN, a cooperative program of the U.S. Forest Service, the four fire agencies of the Department of the Interior, and The Nature Conservancy, supports multi-stakeholder, multi-scalar efforts to restore fire-adapted social-ecological systems (Butler & Goldstein, 2010). Over the past decade, thirteen Native American Tribes have engaged as partners in the USFLN, with the rejuvenation of traditional fire knowledge a direct or indirect result of the expanded focus of restoration of landscapes formerly dominated by traditional fire systems. Participating groups are members of the Apache, Caddo, Crow, Esselen, Ho-Chunk, Karuk, Klamath, Paiute, Pueblo, Shoshone, Warm Springs, Washoe, and Yakima Tribes (Huffman, 2013; USFLN, 2014). Other interagency-tribal partnerships are also expanding. While the rejuvenation of traditional fire knowledge is not the explicit intent, these partnerships are important to increase investment and sense of ownership, enhance social capital and cooperation, and disrupt power dynamics that in the past led to the exclusion of indigenous groups from fire management decisions that have and continue to affect them. These include tribal engagement in Landscape Conservation Cooperatives, collaborative networks designed to coordinate conservation science and better address local and regional concerns, and other region-specific partnerships to help mitigate the effects of climate change and wildfire (reviewed by Voggesser et al., 2013).

With respect to applied traditional fire knowledge integration research in the U.S., perhaps the most notable and relevant work includes ongoing efforts at the U.S. Forest Service Pacific Southwest Research Station in collaboration with the Department of Natural Resources of the Karuk Tribe in California. The Karuk Tribe is currently developing an Eco-Cultural Resources Management Plan that incorporates tribal perspectives, including extensive traditional knowledge of prescribed fire and the landscape's dependence on seasonal fire-induced change (see Lake, 2007; Lake et al., 2010, Karuk Tribe Department of Natural Resources, 2014).

While examples of knowledge integration in U.S. fire management are sparse, a model for integrating traditional knowledge in science-based fire management exists in Australia, where incorporating aboriginal landholders and their traditional knowledge has contributed to more ecologically complete and culturally appropriate prescribed fire regimes. The program is called Caring for Country, a term used to describe the complex spiritual affiliation that encompasses the rights and responsibilities that Aboriginal Australians have with their land. It includes their custodial responsibilities for keeping the land healthy and its species abundant. Caring for Country continues across large sections of the Northern Territory of Australia through customary practice and the Indigenous Ranger Program, and has been described as a "two toolbox approach," which combines traditional knowledge with contemporary land management practices to manage landscapes for their natural and cultural values (see Gorman & Vemuri, 2012; Fitzsimmons et al., 2012; Australian Government Department of the Environment, 2014). Although the Caring for Country model has been the focus of critical analysis (e.g., Wohling, 2009) and is highlighted in numerous debates surrounding the problems and potentials of knowledge integration, it is a long-standing and geographically expansive example of the integration of traditional knowledge and science in fire management. The Caring for Country model may offer many valuable lessons and insights as knowledge integration in U.S. fire management continues to move forward.

VII. Future Work Needed

The case studies and education/outreach initiatives summarized in Section IV. Key Findings reflect the research team's and tribal collaborators' consideration of immediate work needed, for which we are actively seeking to obtain funding.

In a time of rapid environmental and social change, disruptions to fire activity will continue to threaten the integrity and resilience of social-ecological systems around the planet. Our ability to adapt will require reciprocal knowledge exchange, collaboration, and proactive approaches toward bringing together insights from multiple knowledge sources and worldviews. As in other kinds of natural resource management, cross-cultural problem solving about fire is complex, but it is possible. Through this project, we have initiated several new research partnerships and initiatives across the Intermountain West of North America to explore the potentials of knowledge integration for fire and fuels management issues, using PGIS as an organizational platform. We hope to continue to increase dialog and discussion between traditional knowledge holders, fire and fuels managers, scientists, and governing agencies, fostering mutual respect and knowledge sharing that will be sustained beyond the term of this study.

VIII. Deliverables Crosswalk Table

Proposed	Delivered	Status
Literature Review	(1) McBride et al. (manuscript) (Re)new(ed) ways of sustaining the commons: the problems and potentials of integrating indigenous and scientific knowledge in environmental management. (2) Armatas et al. (manuscript) Utilizing traditional phenological knowledge to support management of social-ecological systems vulnerable to changes in climate and fire regimes.	(1) In prep (2) In review (*Ecology and Society*)
Case Study Compilation	See Section IIIC. Compilation of Case Studies of this document, and citation database.	Completed
Set of New Research Hypotheses	See Section IV. Key Findings of this document.	Completed
Research Summary and Tool Description for Wildland Fire Training	See Section I, II, III of this document. See also Website and Technical Documents in citation database.	Completed
Applied Article for *International Journal of Wildland Fire*	(1) McBride et al. (manuscript) Participatory Geographic Information Systems for the integration of tradition and scientific knowledges in fire and fuels management.	(1) In review (*International Journal of Wildland Fire*)
Documentation on MapMe Tool for Wide Distribution	(1) Updated Map-Me website. (2) Huck (technical document) Mapping Meanings (Map-Me) User Manual.	(1) Completed (2) Completed
Other Presentations and Documents	See citation database	Completed and In prep

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X. Additional Reporting (Appendices and other inputs to JFSP)

A. Input into Findings Database (available from www.firescience.gov)

B. Completed Deliverables (entered into citation database at www.firescience.gov)

D. Deliverables Citation Database (items entered into the JFSP Citation Database through July 31st, 2014).

Note: This is a complete list of our websites, presentations, papers, and other documents- both completed and in progress. Most are accompanied by documents and/or links to web postings. Presentations are included that did not result in papers or other documents. Numbers in parentheses at the end of citations refer to the JFSP reference number available at www.firescience.gov.

Websites

http:// map-me.org

Link to the Map-Me survey for Case Study 2: *A case study on climate change impacts to tribal resources (water, vegetation, and fire regimes) in the Jocko Landscape on the Flathead Indian Reservation*. Led by Roian Matt, Forestry Department, Confederated Salish and Kootenai Tribes; Alan Watson, Aldo Leopold Wilderness Research Institute. http://map-me.org/sites/CSKTJocko4/

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Huck, J. 2014. Mapping Meanings (Map-Me) User Manual. (7526)

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Sanchez-Trigueros, F. et al. (manuscript). Embedding participatory GIS at the interface of environmental science and traditional ecological knowledge: a soft systems approach.

Sanchez-Trigueros, F. (manuscript). The treatment of multimodal data in GIS technologies: setting up smart geodatabases for the retrieval of fuzzy information.

Sanchez-Trigueros, F. (manuscript). Analyzing positional vagueness in practice: non-parametric techniques for the statistical modeling of fuzzy locations.

Sanchez-Trigueros, F. (technical report) SEMA: Semantic Mapping Information System. Software language and specification. Version 1.0 Beta.